# First Order Modeling of Cannon Fire Out-of-Battery (FOOB) Recoil Dynamics

**Presented**
**at the**
**39th Annual Guns & Ammunition/**
**Missiles & Rockets**
**Symposium & Exhibition**

**13-16 April 2004**
**Baltimore, Maryland**

**David C. Rutledge, Ph.D.**
**Jeffrey V. Ireland**
**United Defense**

# Motivation for FOOB Analysis

United Defense

- **Transformation initiatives: Lightweight vehicles with high performance weapon systems**
- **Firing high performance cannon imparts a large acceleration on the vehicle and crew**
- **These accelerations must be managed for the vehicle and crew to fight effectively**
- **Fire Out-of-Battery (FOOB) analysis is an important tool in designing towards this goal**

# Overall Description of FOOB Analysis

United Defense

- This presentation will describe the FOOB analysis for a conceptual 105-mm cannon
- Developed an equation-based parametric model to predict performance envelope for an ideal FOOB cannon
- Used chamber pressure data from an APG FOOB test firing to validate model
- Used data from Interior Ballistic High-Velocity Gun 2 (IBHVG2) interior ballistic model to generate pressure profile for highest energy round
- Inserted profile into parametric model to predict performance envelope for highest energy round

# Phases of FOOB Cannon Operation

**Cannon operation can be broken into 3 phases:**

1. **Time from unlatching to round firing – cannon accelerates forward**
2. **Time from firing to end of firing impulse – cannon decelerates to zero velocity while reaching full stroke, then accelerates backward**
3. **Time from end of impulse to relatching – cannon decelerates**

# Detailed Description of FOOB Calculation

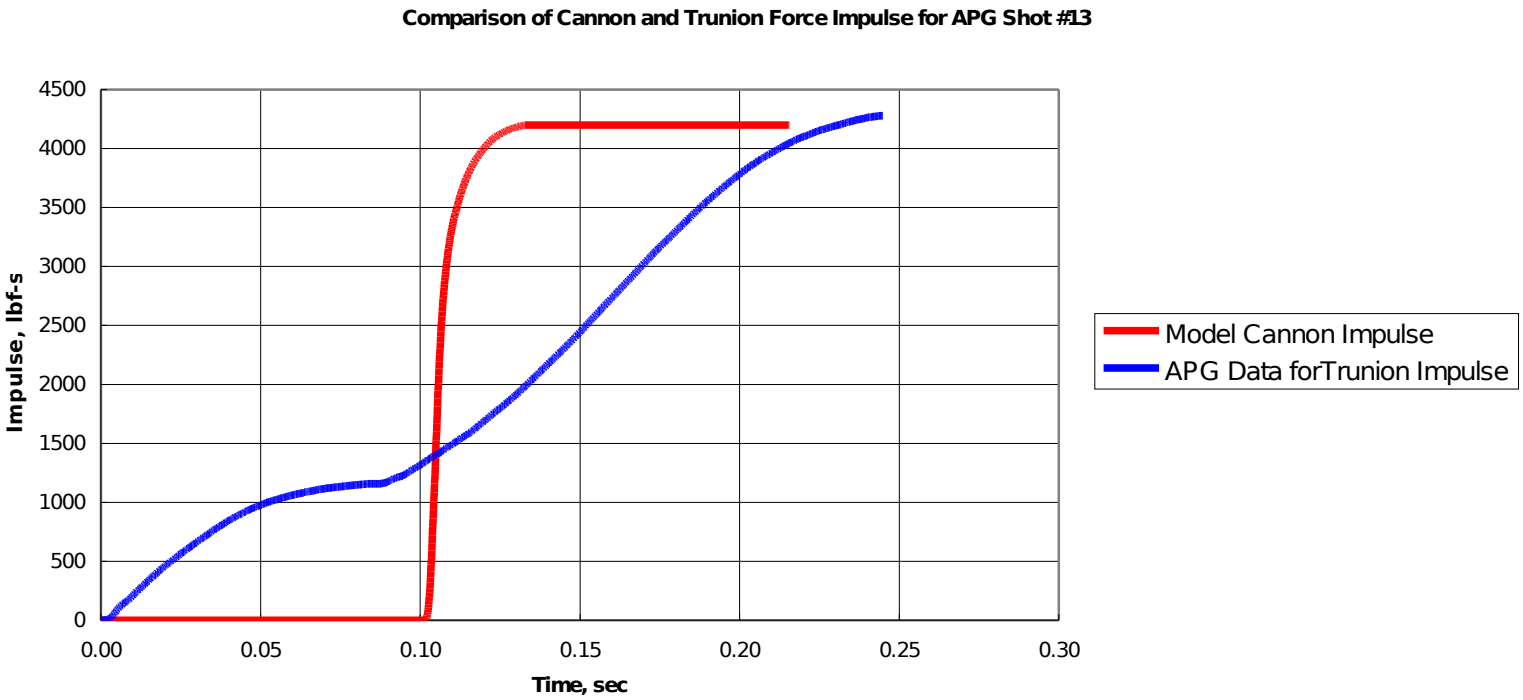
United Defense

- This is a spreadsheet based parametric calculation
- Peak trunnion force is what determines the peak crew acceleration
- Forward force applied to the trunnion when the cannon is moving forward is less than or equal to the forward force applied to the trunnion when the canon is moving rearward
- Force ratio is the ratio of those two forces
- Trunnion force-time history is optimized using solver so cannon barely has enough energy to relatch
- Model runs made for different values of recoil stroke, force ratio, and elevation angle
- Assume that there are no frictional or other energy losses

# Model Validation Using Test Data

United Defense

## Impulse vs. Time




**he total impulse of the ideal model and the test are essentially the sam**

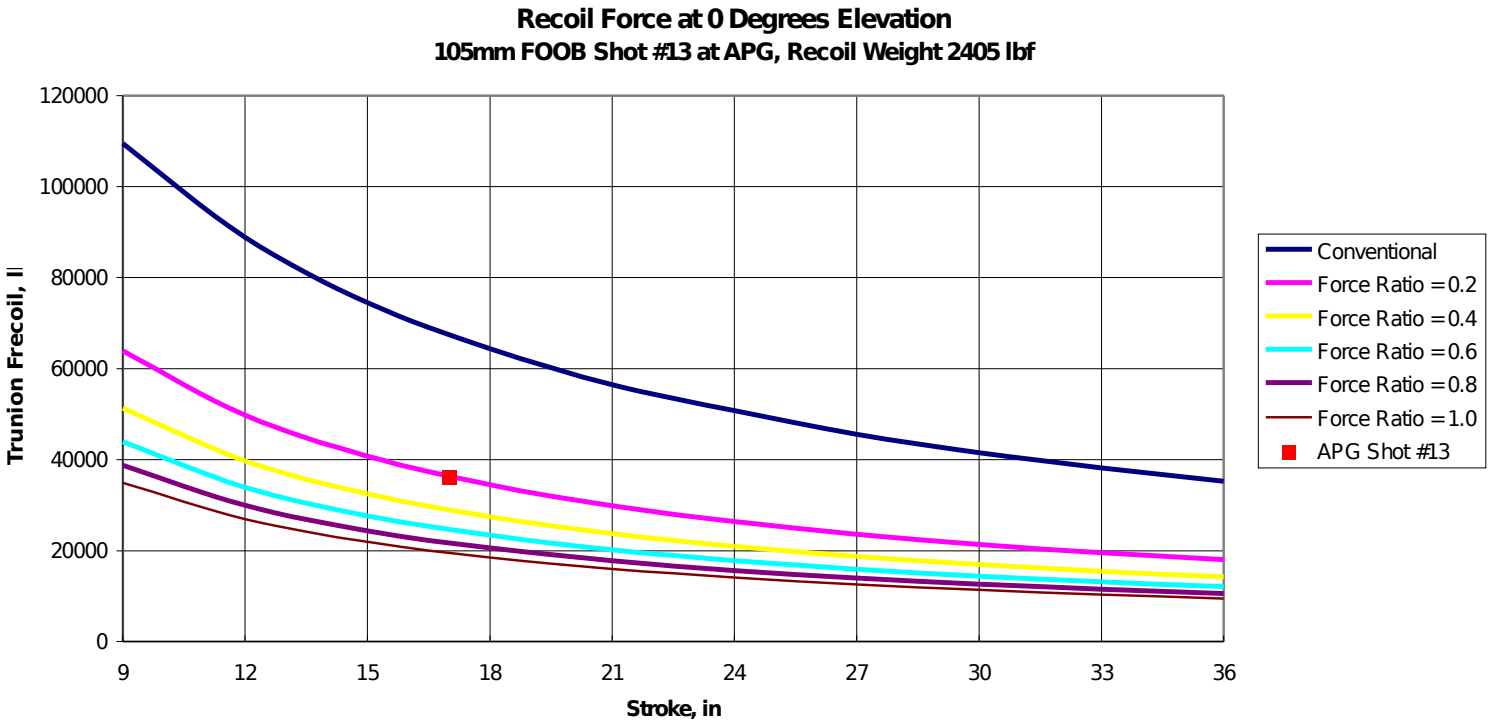
# Model Validation Using Test Data

## Trunnion Force vs. Time

**The ideal model force–time curve is rectangular, (i.e., the force is not constant with respect to time)**

# Model Validation Using Test Data

## Max Trunnion Force vs. Recoil Stroke




**Higher values of force ratio result in lower trunnion forces**

# Results of Model Validation

United Defense

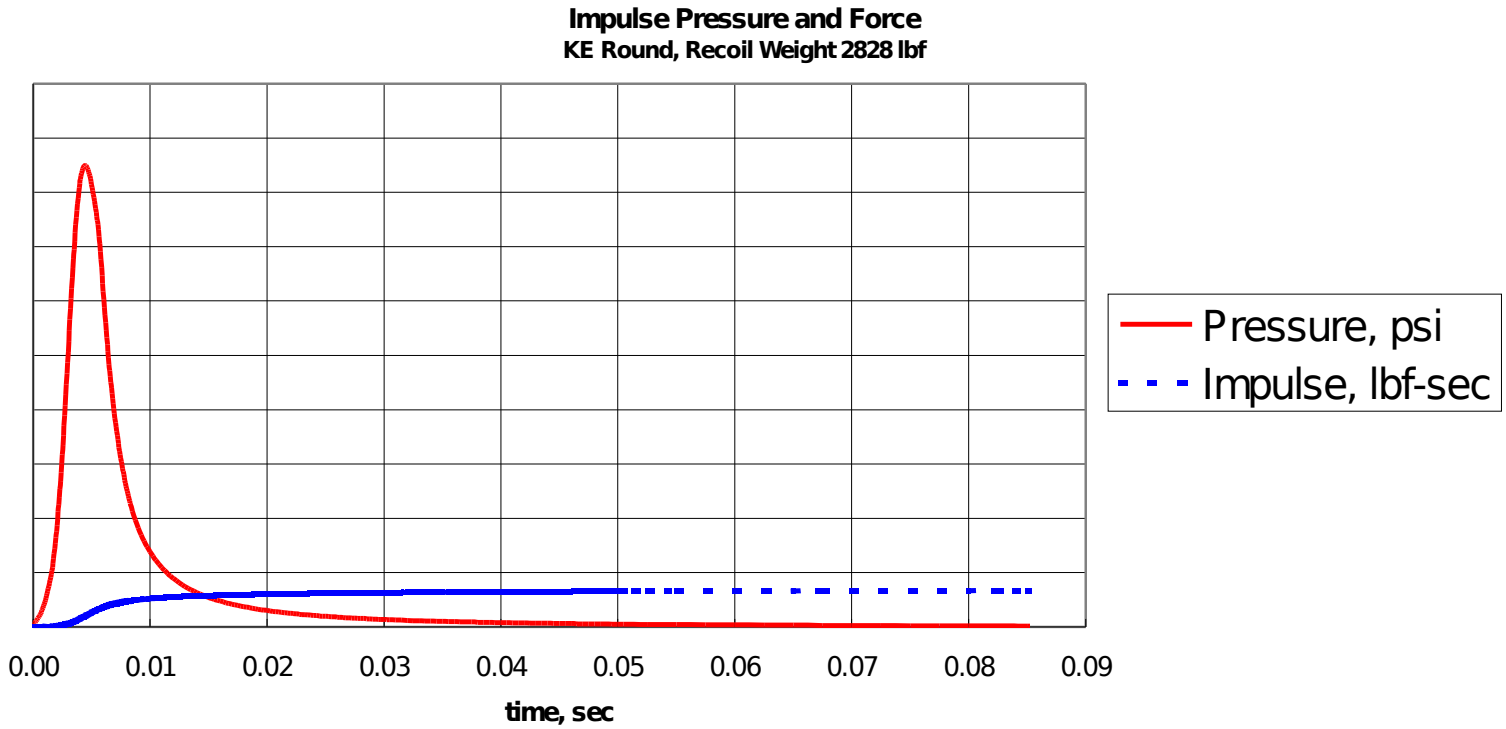
- **Model envelope shows results of an ideal system, forming a lower bound on actual system results**
- **Test forces are higher than model predicted forces since test forces are not rectangular**
- **Even well engineered conventional recoil systems will have a significantly higher trunnion force than predicted**
- **Further model refinement would yield results closer to the test data. As a first approximation, the model times a multiplying factor predicts a real gun's performance**

# Model for Highest Impulse Round

- The model is next used to predict the trunnion loads for the highest impulse round planned for the conceptual 105-mm cannon
- IBHVG2 run generated a ballistic pressure profile, based on the known parameters for the highest impulse round (units not shown)
- FOOB model uses this as part of its input deck, along with other parameters such as recoiling mass, recoil stroke, and bore diameter
- Results are then plotted for different strokes and force ratios

# Highest Impulse Pressure Curve

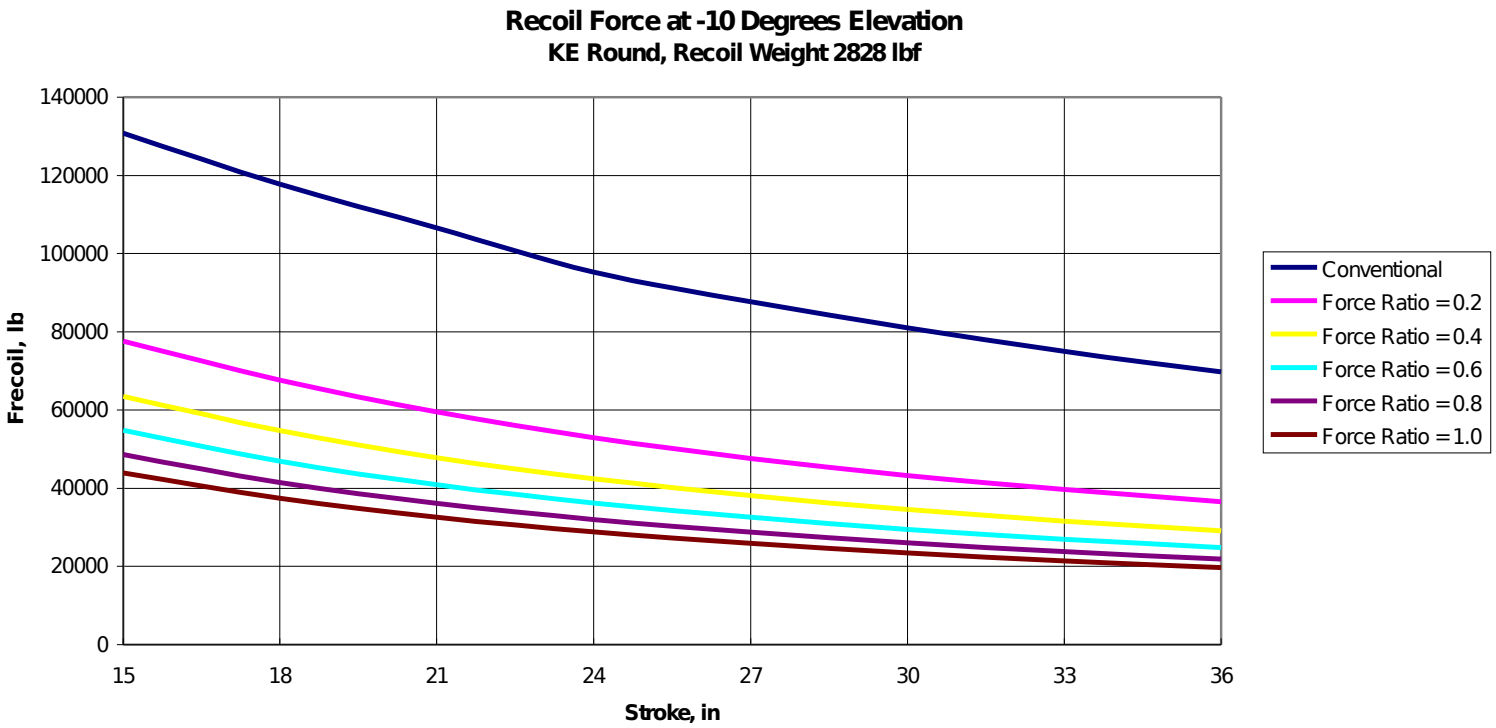





**Proprietary data: Pressure and impulse values not shown**

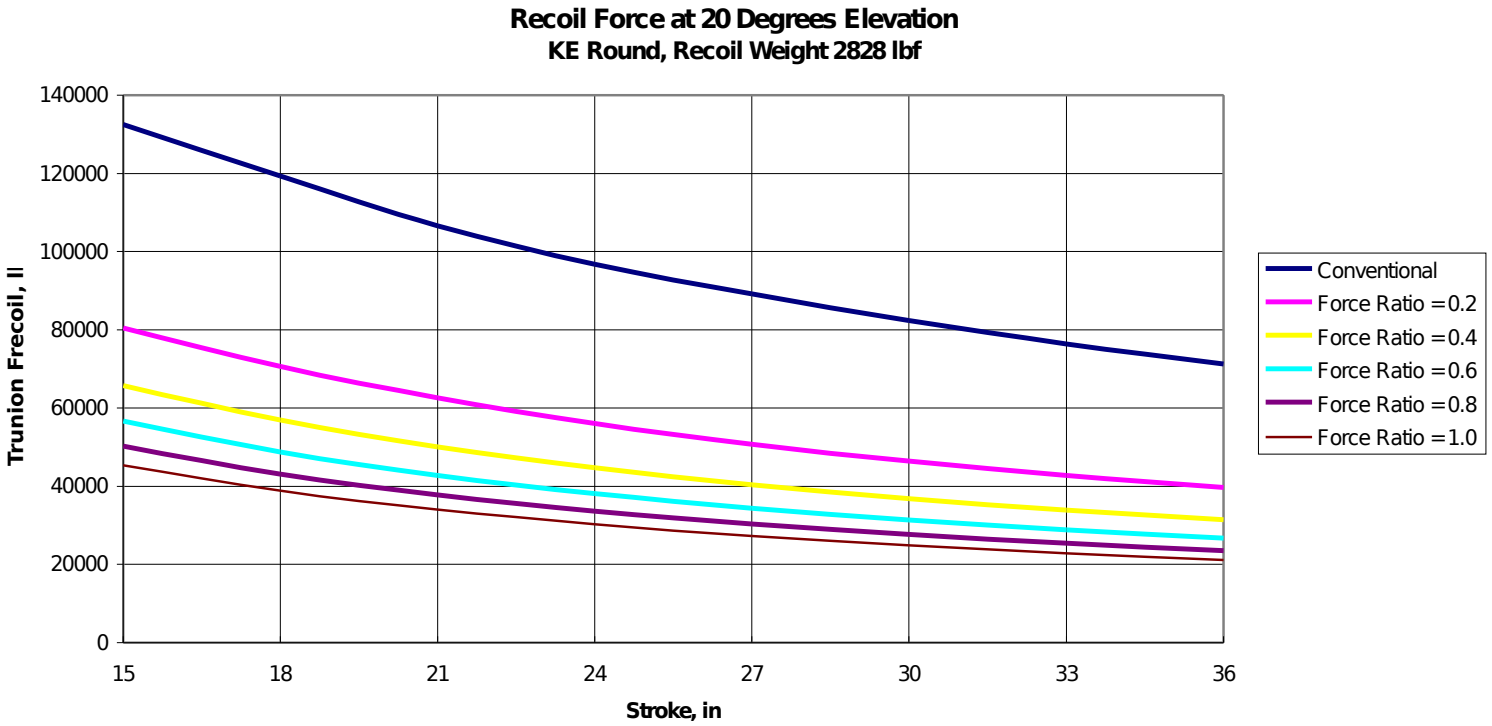
# Max Trunnion Force vs. Stroke

## Highest Impulse Round at -10 Degrees Elevati



# Max Trunnion Force vs. Stroke

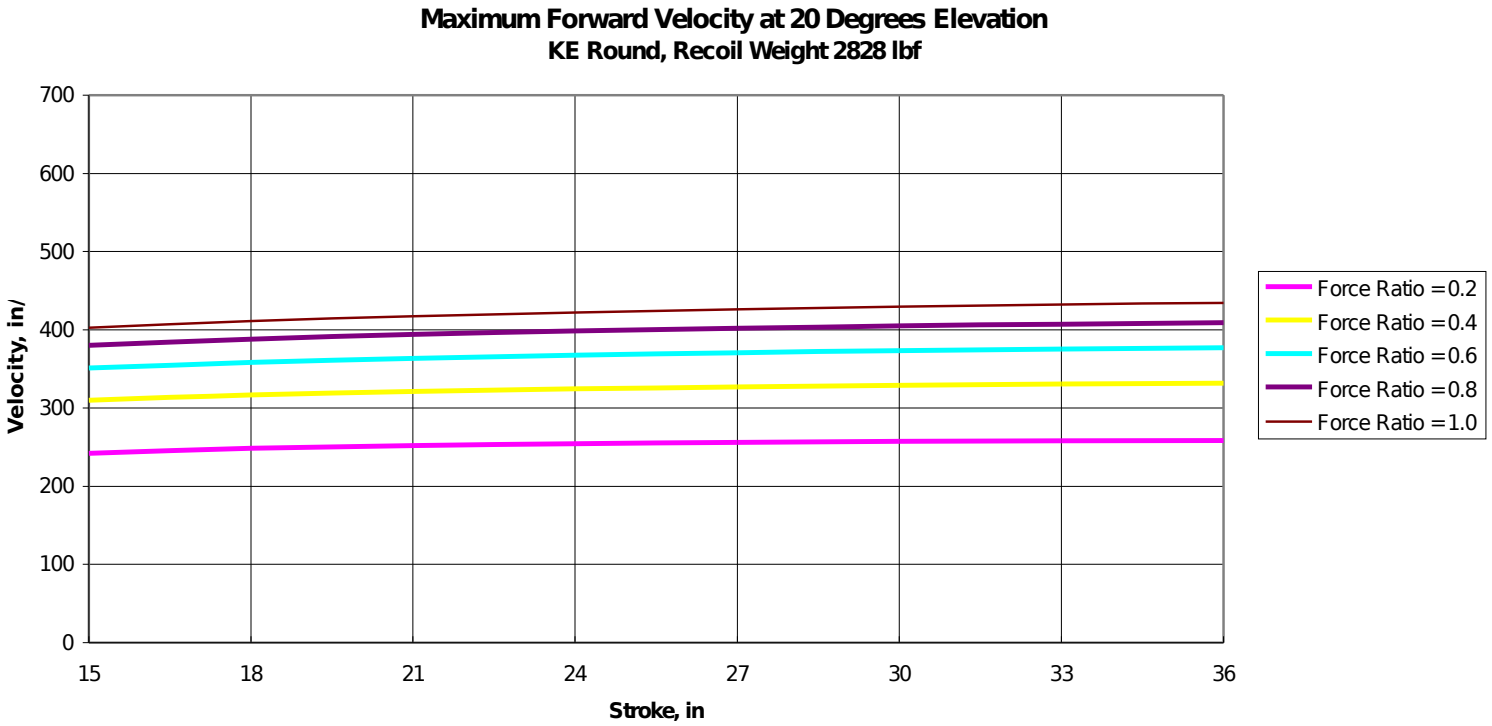
## Highest Impulse Round at +20 Degrees Elevat




**Cannon elevation has minimal effect on maximum trunnion force**

# Forward Velocity Curve

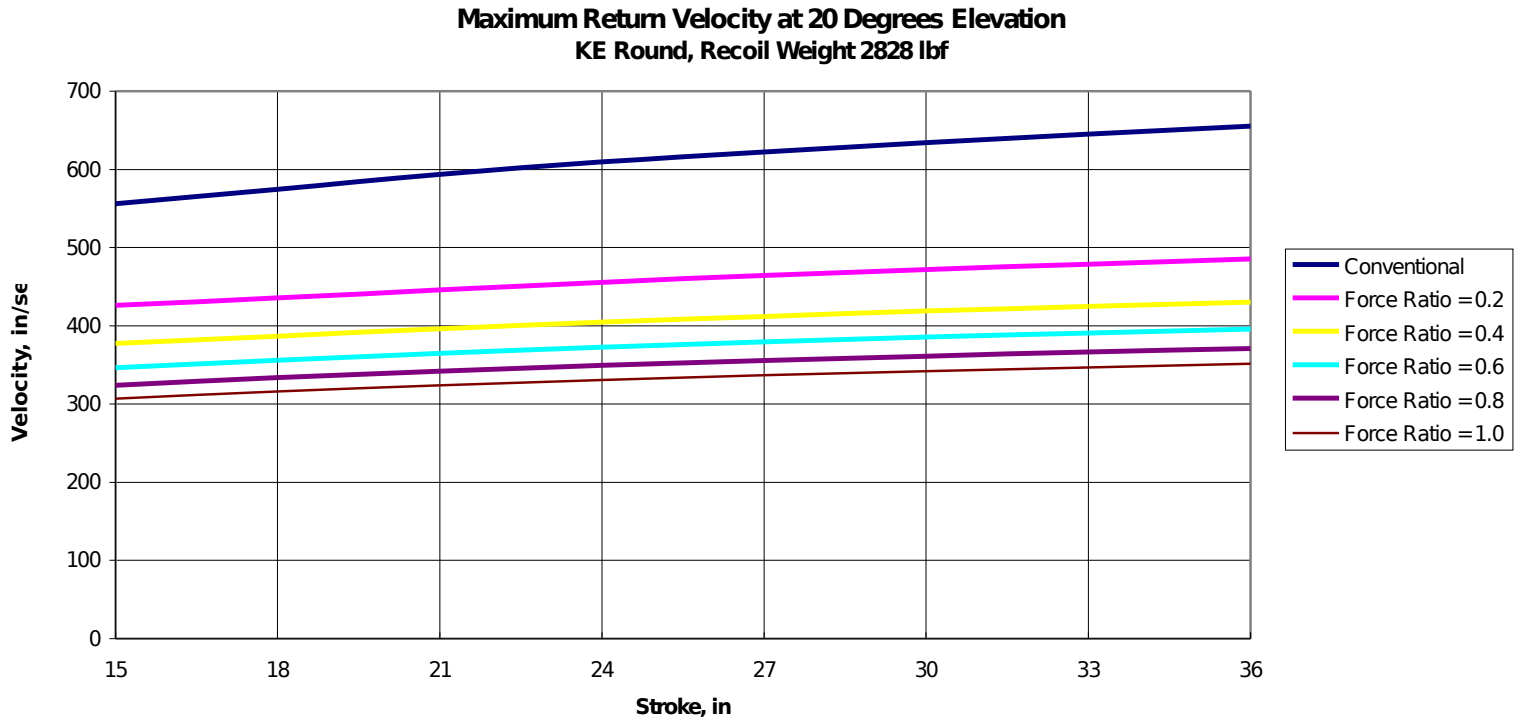
## Maximum Forward Velocity



# Return Velocity Curve

United Defense

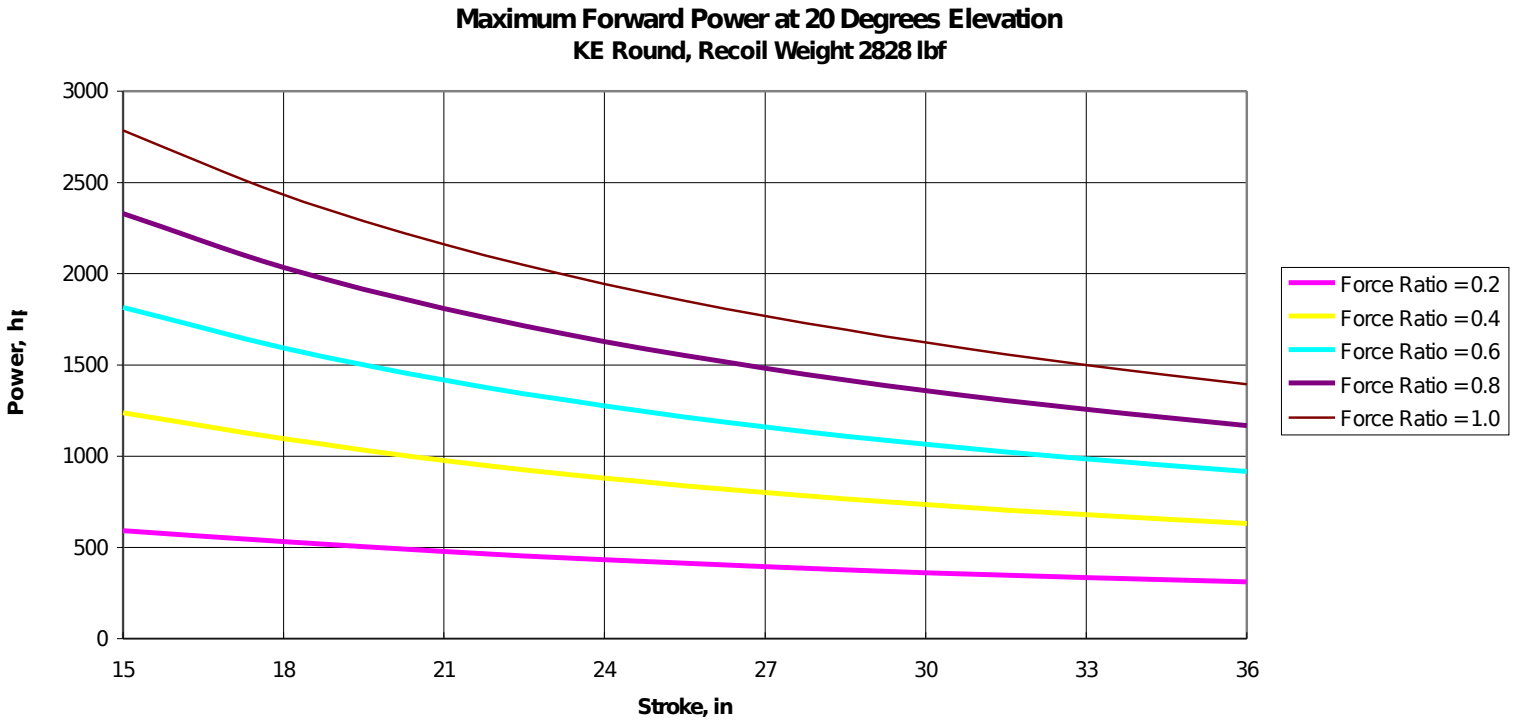
## Maximum Return Velocity




**Return velocity is significantly higher than forward velocity**

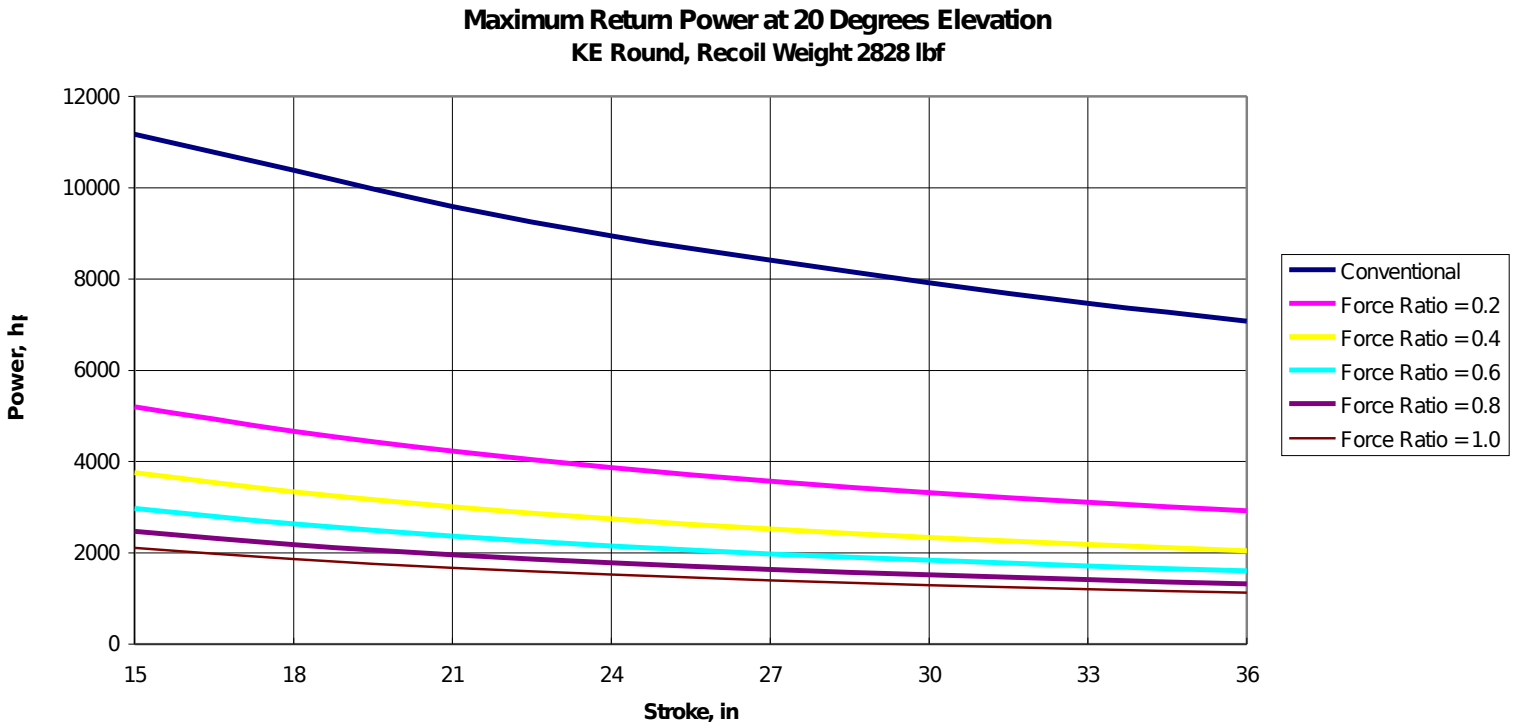
# Forward Power Curve

## Maximum Forward Power Requirement



# Return Power Curve

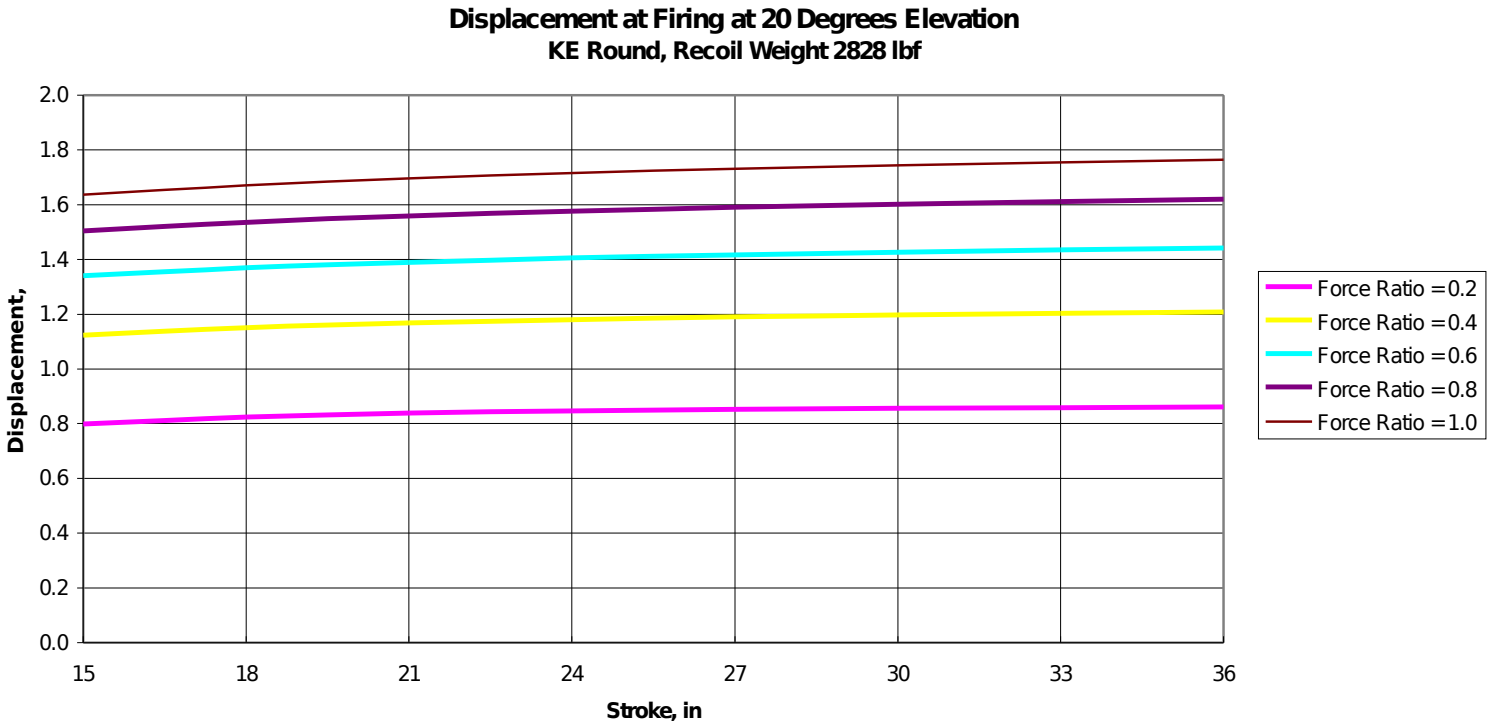
## Maximum Return Power Requirement




**Maximum return power to be absorbed is significantly higher than the forward power that needs to be supplied**

# Displacement Position at Firing

## (From In-Battery Position)




**Displacement from in-battery position at firing is greater for higher values of force ratio**

# Analysis of Results: Highest Impulse

- Increased recoil stroke and force ratio are critical towards reducing trunnion force
- Even a small force ratio can greatly reduce trunnion force
- Stroke influence is greatest for short recoil stroke designs
- Longer recoil strokes minimize the trunnion force by allowing higher forward velocities (as opposed to higher masses) to generate forward momentum
- The power to accelerate the cannon forward can be generated from the stored recoil energy of the previous shot.
- A percentage of both forward and return power will be converted into heat, which must also be managed

# Analysis of Results: General

United Defense

- Calculations can be performed for conventional cannons as well as FOOB cannons by varying the initial conditions (no forward momentum at initiation)
- Analysis results will be more accurate as a cannon design matures
- Limited test results will allow increased model validation and refinement
- This model is also used to predict forces and firing times for the lower impulse rounds (see backup slides)

# End of Presentation

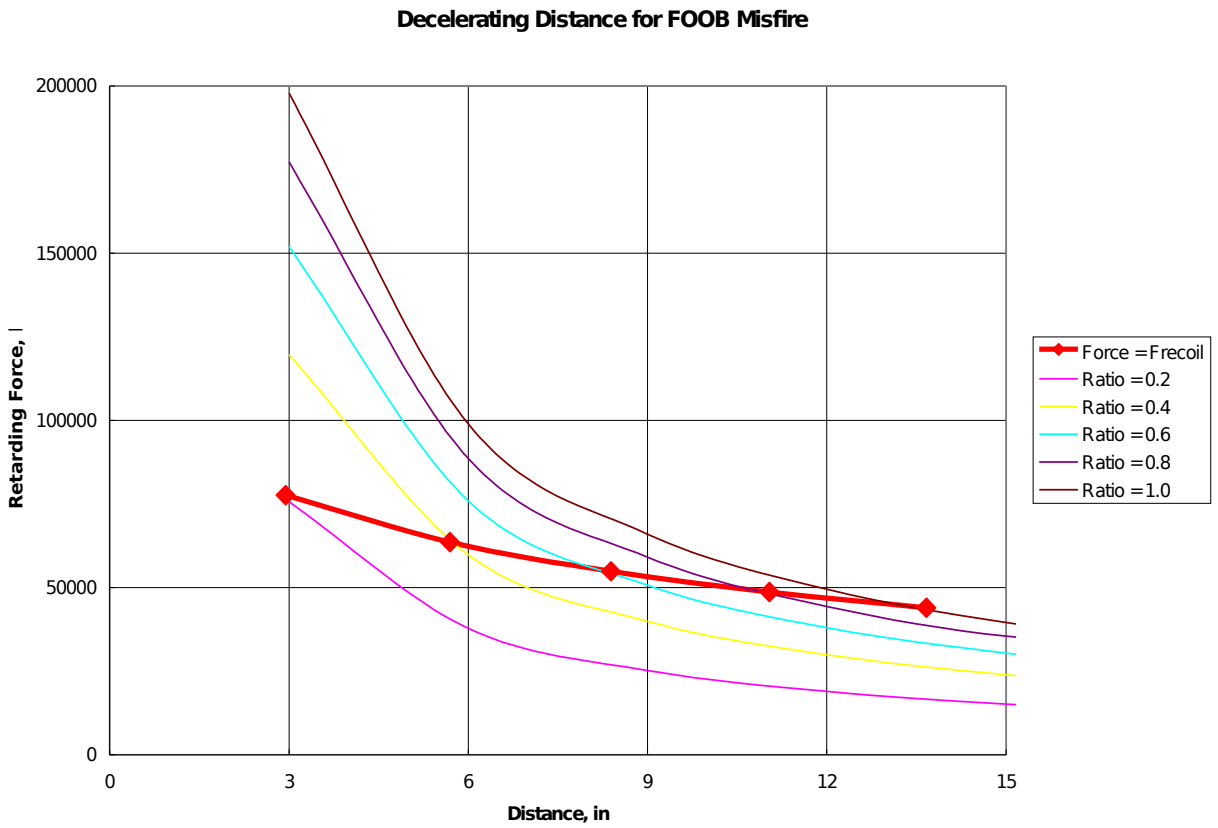
United Defense

# Questions?

# Back-up Slides

# Misfire Deceleration Distance

United Defense

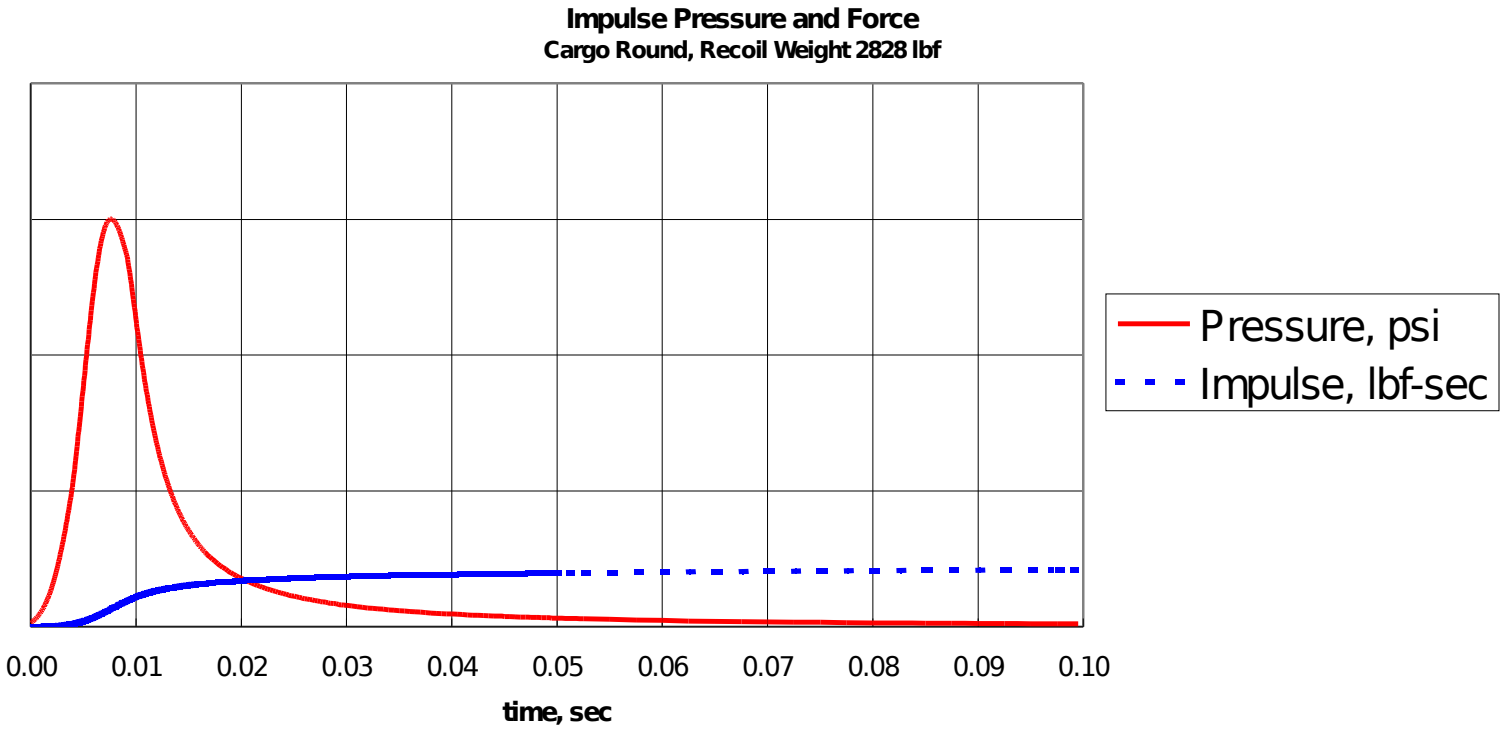


# Model for Cargo Round

United Defense

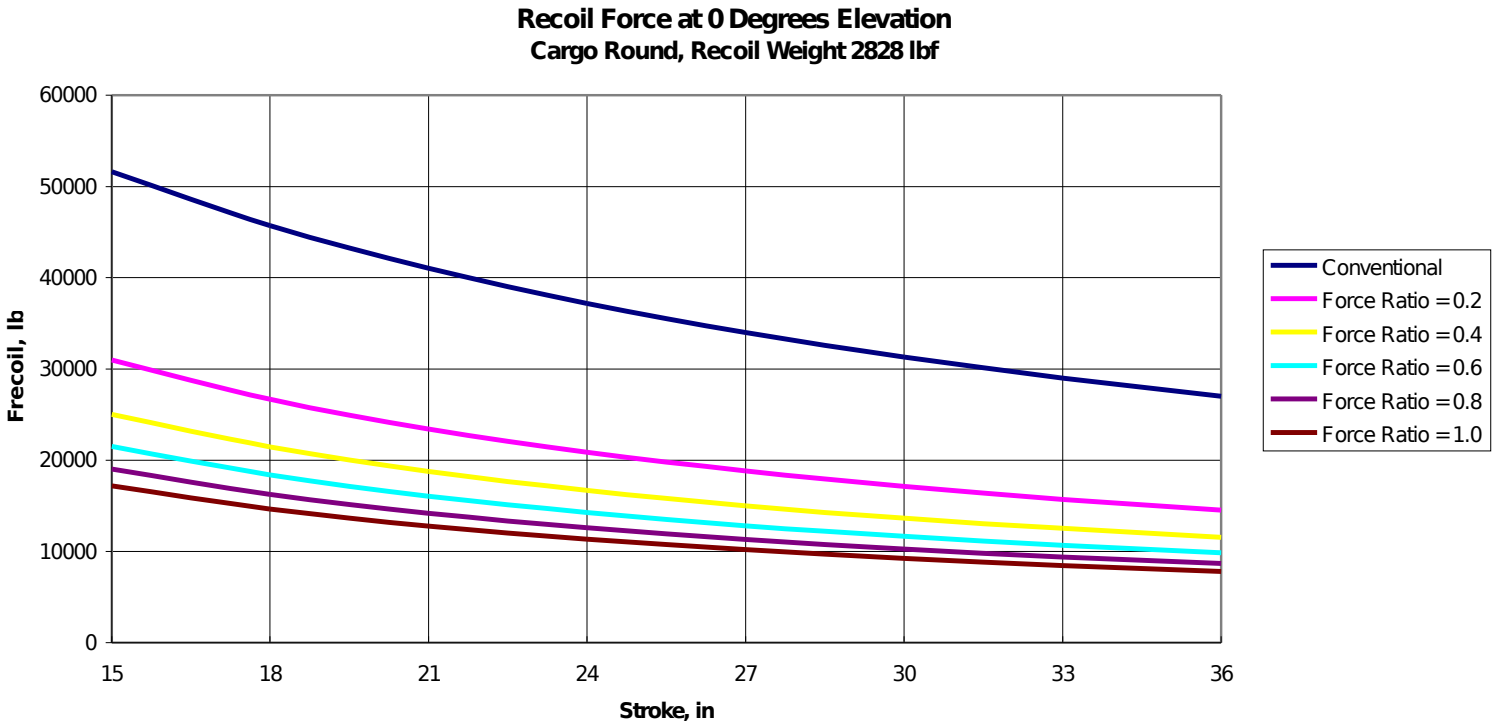
- **The model is used to predict the trunnion loads for the cargo round using the same approach as before approach:**
  - The cargo round has a lower impulse
  - The cargo round is fired at higher elevation angles

# Cargo Round Pressure Curve



# Trunnion Force vs. Stroke

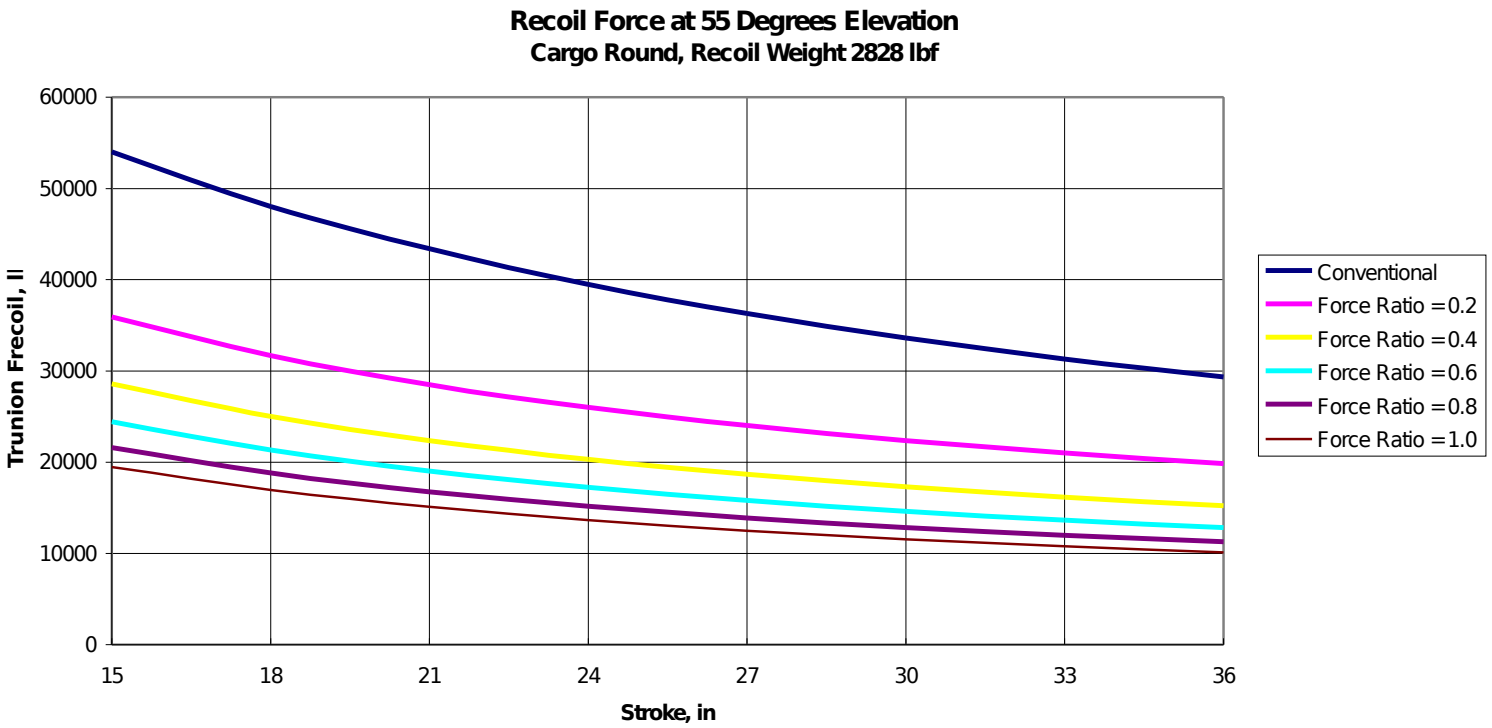
## Cargo Round at 0 Degree Elevation



# Trunnion Force vs. Stroke

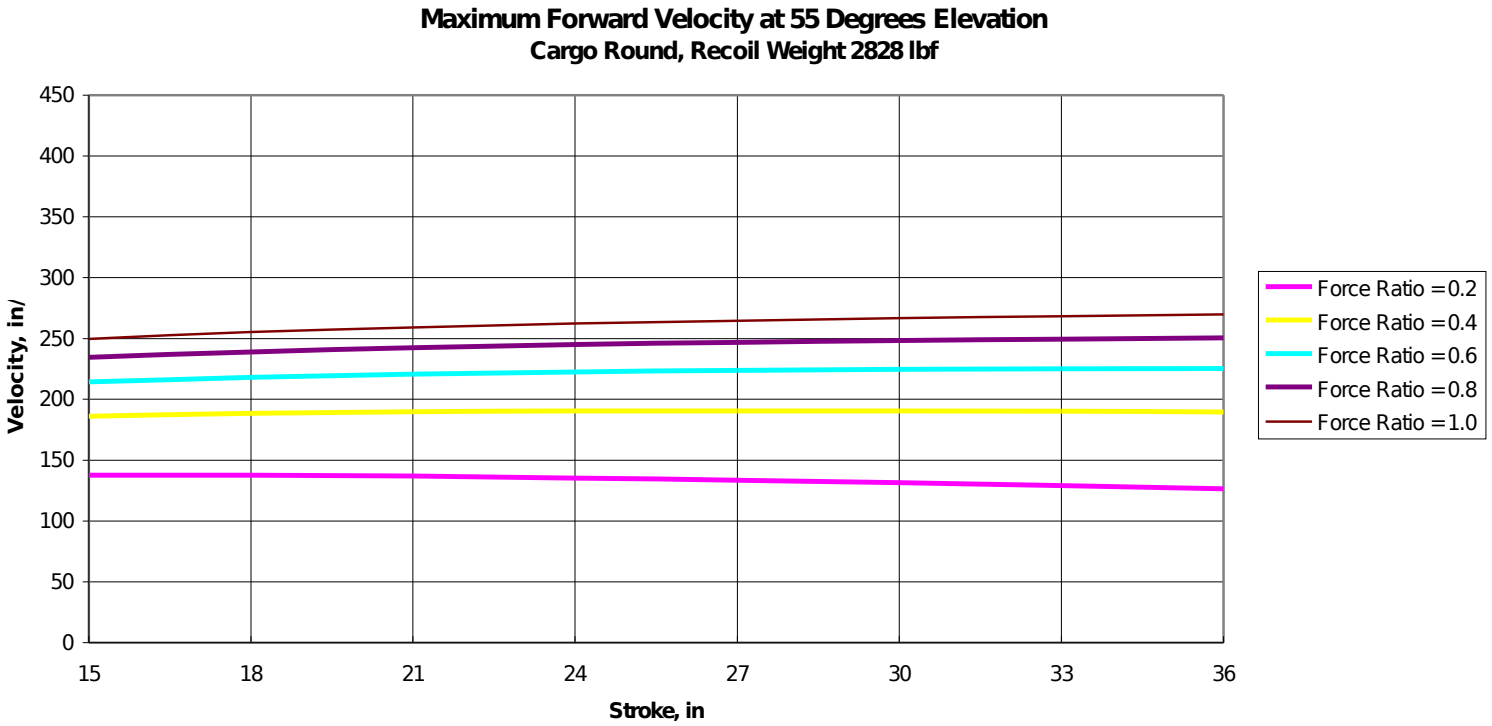
United Defense

## Cargo Round at +55 Degrees Elevation



# Forward Velocity Curve

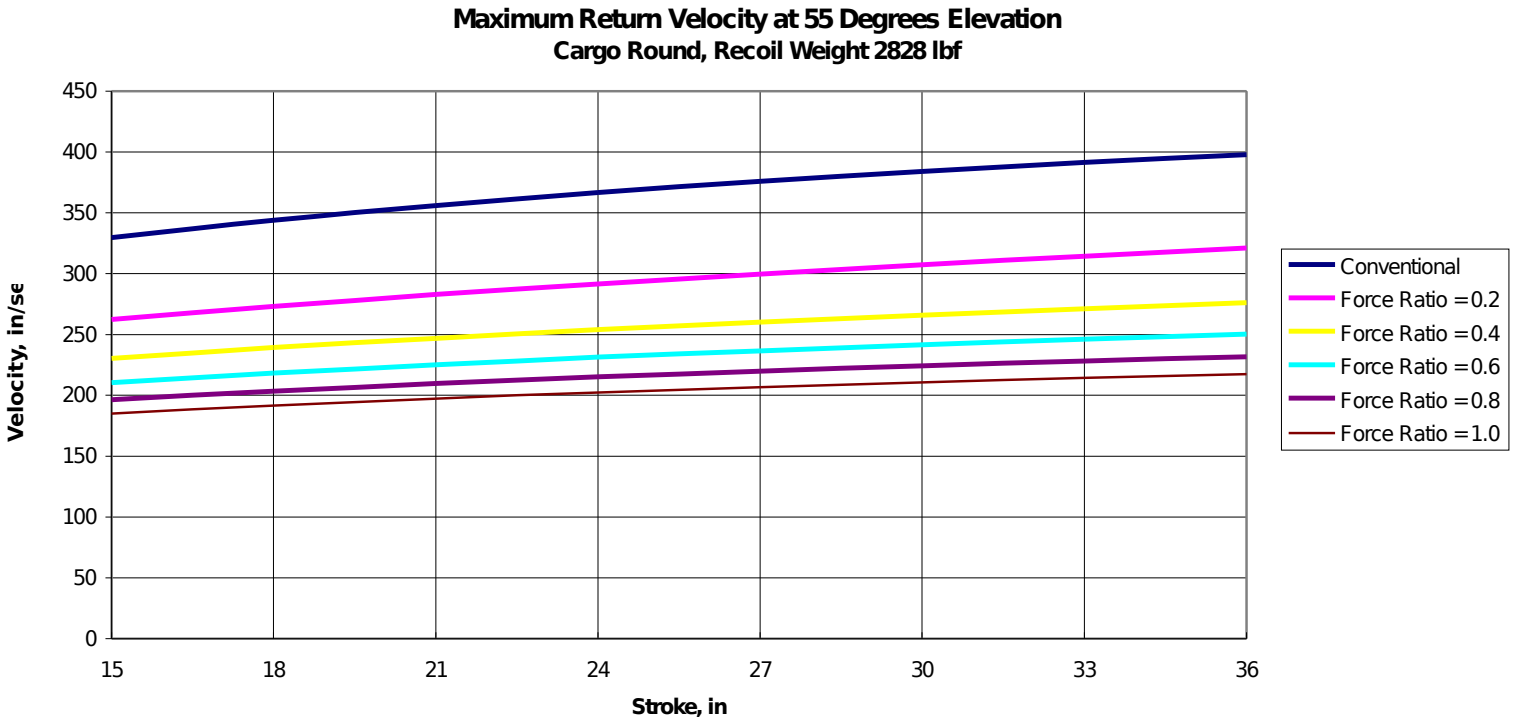
## Maximum Forward Velocity




**To minimize the trunnion force, higher velocities are required for longer stroke values**

# Return Velocity Curve

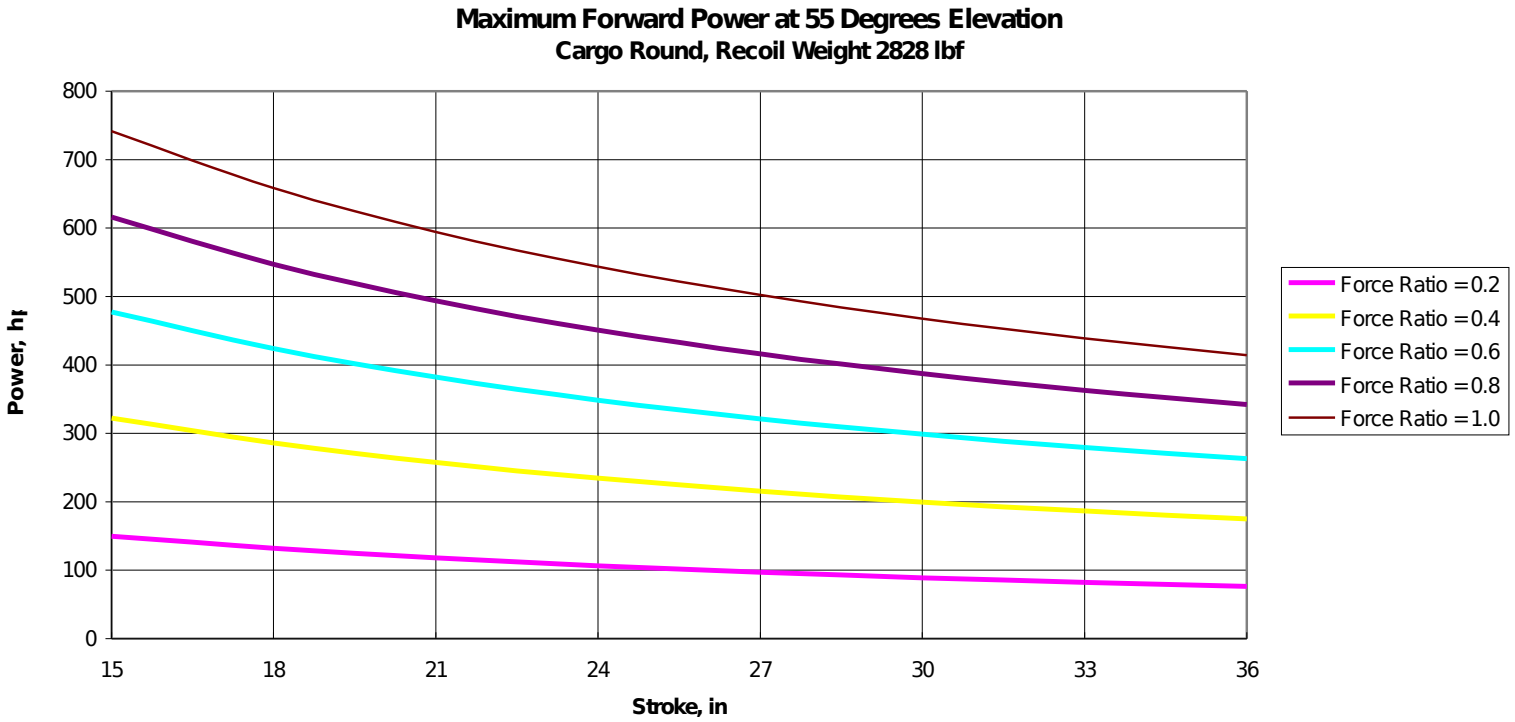
## Maximum Return Velocity



# Forward Power Curve

United Defense

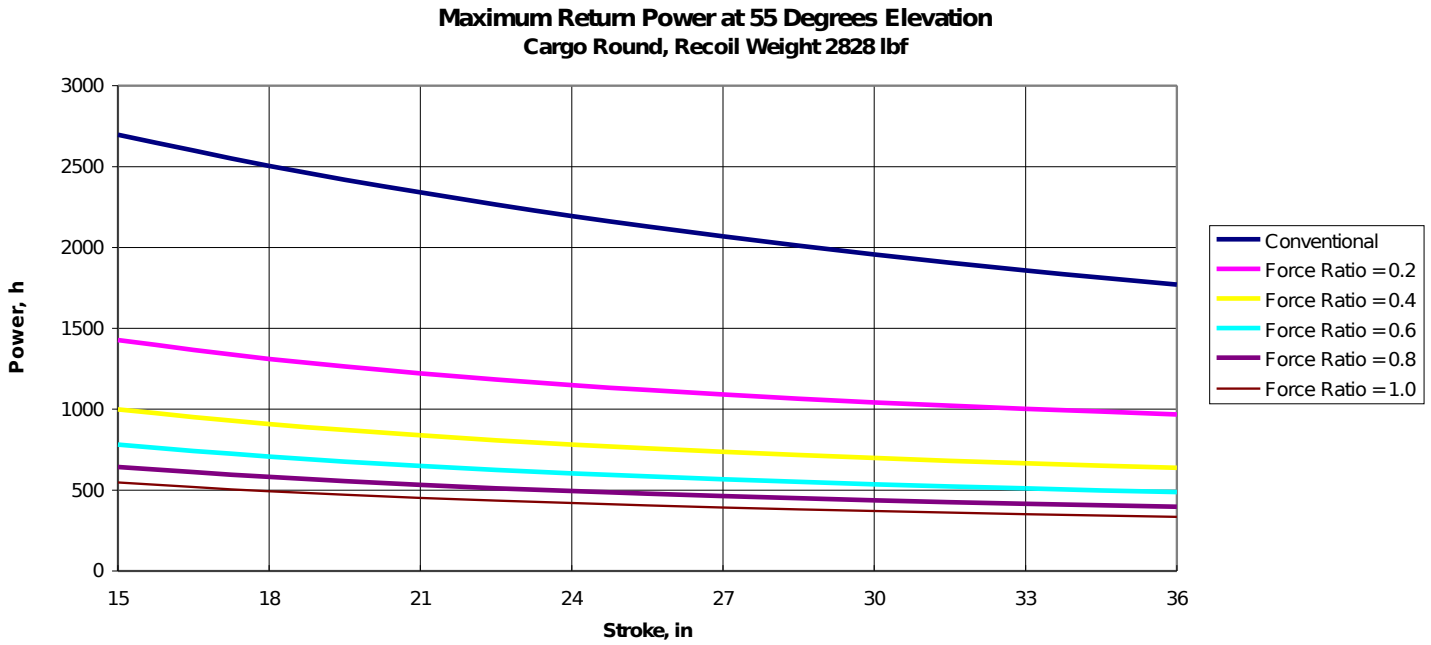
## Maximum Forward Power Requirement




**This forward power will probably be generated from the stored "recoil" energy of the previous shot.**

# Return Power Curve

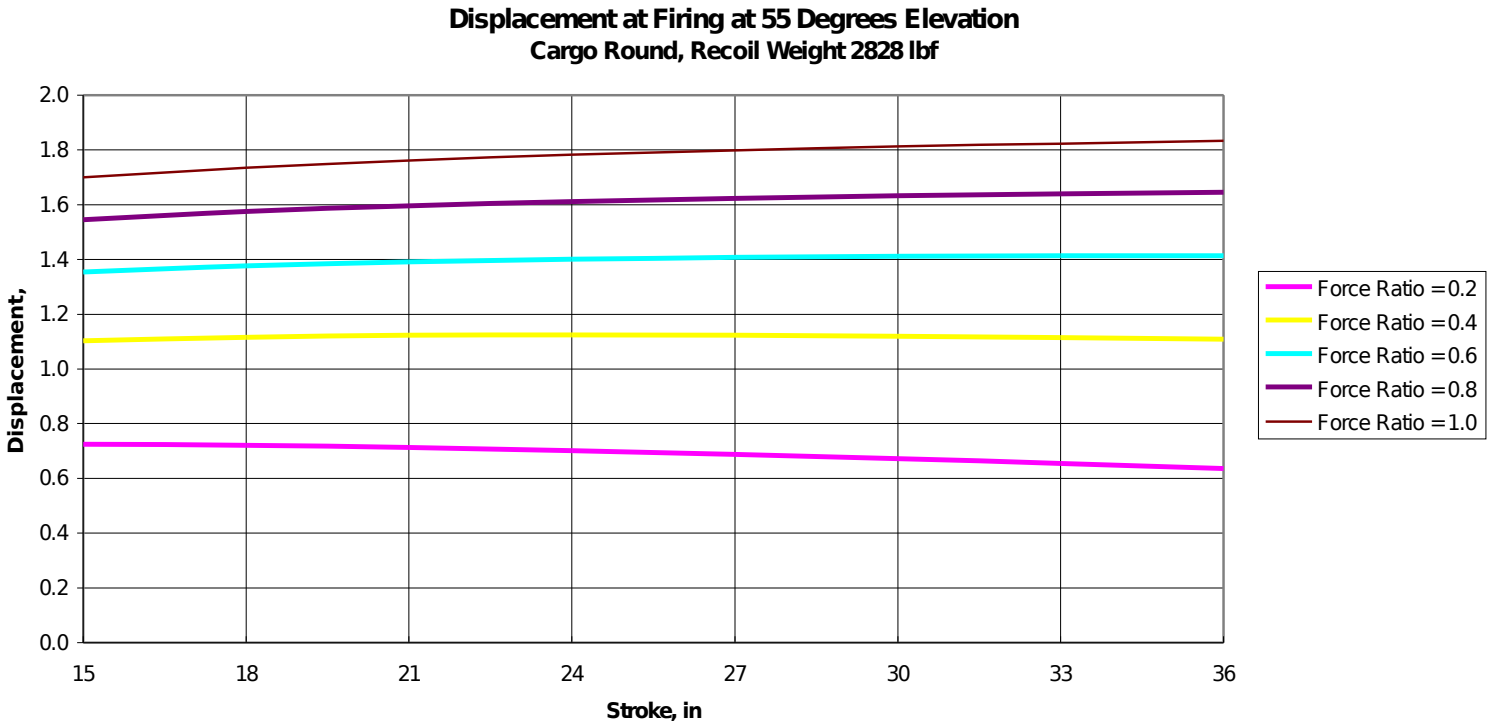
## Maximum Return Power Requirement




**A percentage of both forward and return power will be converted into heat, which must also be managed.**

# Displacement Position at Firing

## (From In-Battery Position)



# Misfire Deceleration Distance

United Defense